

iv. Tolerances

Transfer of a beam from the AGS to a RHIC ring will in general affect its quality adversely. The deterioration may be the result of the mislocation of a bunch's center of charge relative to its intended synchronous fixed point in 6D phase space, or of a mismatch between the 6D emittance of a bunch and the lattice functions of the ring in which it is to circulate. Tolerances must be established to ensure that such deterioration can be kept within accepted bounds. Some of these tolerances can be relaxed if means are provided for error correction after injection. Dipole errors, i.e., errors in position or direction, and energy or phase, can be corrected to some extent by transverse or longitudinal dampers, which have to be present anyway for the control of beam instabilities.* Normally such dampers are not particularly powerful, since they are intended for damping of coherent motion with very small amplitude. The required power is proportional to the square of the maximum error because the correction must be completed in a time that is small compared to the decoherence time of the error motion, and it turns out that even modest errors require considerable power.* The critical injection magnets and their power supplies are presently being designed with a view to minimizing their contribution to the error budget. Design guidelines are adopted which ensure that the correction capability of the transverse dampers, assumed to encompass orbit error amplitudes of up to 2 mm inside RHIC, is not exceeded.

As far as pulsed magnets are concerned (kickers, septum magnets, orbit bumps), systematic pulse-to-pulse variations are assumed to be tolerable, provided that together they contribute less than 1 mm to the injection orbit error amplitude inside RHIC, well within the damping system capability. The same overall maximum allowance is made for the contributions from all other dc dipole magnets in the transfer line combined. Thus, the overall requirement for the transverse damping systems of RHIC is to damp out orbit error amplitudes of less than 2 mm. Assuming that about six such error terms from the pulsed

* J. Rose et al, *The Conceptual Design of the RHIC rf System*, Report RHIC/RF-22 (1994).
S. Peggs et al, *Collective Instabilities in RHIC*, Report RHIC/AP 36 (1994).

Table 5-2. Parameters and Tolerances of Beam Transfer

	Beta m	Angle mrad	Tolerance % max
AGS Kicker	15	2	0.9
AGS H-10 Septum	15	22	0.09
AGS Orbit Bumps	22	2	0.8
Switch (X-Y)	54	48	0.02
RHIC Kicker	31	1.9	0.7

systems contribute, that the errors are not correlated, and that vertical and horizontal deflections contribute in equal strength, one may specify that each component can contribute not more than $1/\sqrt{6}$ times the overall allowance. With this requirement, one obtains the systematic error budget for pulsed magnets which is listed in Table 5-2.

Systematic error contributions from other dc dipole magnets in the transfer line, of which there are many, are specified low enough so that together they contribute no more than what is allowed for the pulsed components.

Random noise while the beam passes through each magnet, i.e. during a time interval of 20 nsec or less, is expected to enlarge the beam emittance incoherently, and it cannot be damped out. If one views this incoherent growth as being the result of mixing of Gaussian error probabilities with a basically Gaussian density distribution of the beam, one may prescribe a random noise tolerance for each component which keeps the overall emittance growth within acceptable bounds. For example, if the final invariant emittance of 10π mm mrad is to be the result of a dilution of no more than 10% (from 9 to 10π mm mrad), one obtains noise tolerances about 50% wider than the systematic tolerances given in Table 5-2. As a practical matter, only the fast kicker systems contribute sufficiently fast random noise to be of any concern, and the septum magnets and other pulsed systems, as well as the dc components, contribute totally negligible noise.

Similarly, quadrupole excitation errors in the transfer line will cause mismatches with respect to the RHIC lattice, which will lead to an effective enlargement of the beam

emittance in the collider. Although this mismatch will be minimized by tuning the optics of the line, variations cannot be tracked and corrected from pulse to pulse. Quadrupole power supply tolerances are specified to ensure that the emittance variations from this source alone are unlikely to exceed a few percent.

The principal causes for dilution in longitudinal phase space are errors in the phase between bunch and bucket centers and mismatches between the synchronous energies in the AGS and RHIC. Keeping the longitudinal emittance blowup within 10% requires the time error to be less than 0.07 of the rms bunchlength of 3.4 nsec, i.e. within ± 0.24 nsec, and the difference between the synchronous energies to be within $\pm 2.6 \times 10^{-5}$. It is expected that these conditions will be met by the basic hardware. However, if this appears to be unachievable, a longitudinal damper could be used. That damper system would have to be designed to correct energy errors of the order of 2.5×10^{-5} by an order of magnitude. However, it is quite possible that the uncorrected injection momentum errors will be as large as 10^{-4} , and the design parameters for the longitudinal damping system have been determined to accommodate this error.